Comparison of 3D Scanned Human Models for Off-Body Communications using Motion Capture

S. Swaisaenyakorn, P.R. Young, S.W. Kelly and J.C. Batchelor
School of Engineering and Digital Arts
University of Kent
Canterbury, Kent, UK
ss638@kent.ac.uk, p.r.young@kent.ac.uk, s.w.kelly@kent.ac.uk and j.c.batchelor@kent.ac.uk

Abstract—**Body area networks are complex to analyze as there are several channel mechanisms occurring simultaneously, i.e. environmental multipath together with body motion and close coupling between worn antennas and human tissue. Electromagnetic (EM) simulation is an important tool since not all studies can be done on a real human. In order to gain insight into off-body communication involving a worn antenna, this paper uses a 3D animated model obtained from a 3D surface scanner and a motion capture system for full wave simulation of channels at 2.45 and 5.5GHz. To evaluate if the model can represent body area radio channels in general, a comparison of S21 of the simulated model with measurements from 5 other models of similar height to the main test subject is presented.**

Keywords-component; 3D animated human model; motion capture; body area network

I. Introduction

Wireless body area networks have become more popular due to the great flexibility that they have introduced to daily life. This includes, but is not limited to, healthcare monitoring, entertainment, personal trainer systems, and mobile equipment for military personnel. In these applications, the critical level of the signal outage transmitted between devices is different. Low outage is required in applications such as healthcare monitoring and personal military applications since this can compromise the health or safety of a user, while higher outage can be tolerated in other, non-critical systems. Hence, knowing the radio channel condition is important for the efficient siting of antennas on body and the calculation of link budgets. This is important not only for achieving the necessary bit error rate, but also to prolong battery life and reduce the exposure of the user to microwave radiation.

Over recent years, many research groups, for instance, [1-5], have studied body area network radio channels when human bodies in various gestures rather than in the standing position. The work has illustrated how different body gestures can influence the radio channel. These studies were done using both measurement on real humans and with simulation on numerical models using commercial full wave simulators.

In [1-3], a commercial avatar program called 'Pozar' is employed which provides animated movable phantoms. It is quite difficult to guarantee that the physical and numerical models perform exactly the same actions and some care is required to match video frames when posing the avatar. This was done by a human test subject having to try to repeat the exact movement that the 'Pozar" model does. Although, [1] has used video recording technique to help improving the similarity of the movement between the two models, the difference in terms size between the human model and the "Pozar" model is also an important issue that can cause discrepancy between measurement and simulation. Additionally, the placing of the antenna(s) on the body is an informed guess as the exact relative orientation of the antenna and separation from the skin is not known.

The authors have overcome this problem by proposing a method of creating a 3D animated model on which the radio channels are solved using XFdtd (the EM simulator chosen in this study). The created avatar comprises a 3D surface scan of the test human subject together with movement data of the same human captured by a motion capture system. The body area network radio channel is measured while the motion capture is taken. Furthermore, the position of test antennas is also tracked by the motion capture system [6].

The measurements were taken using two dual band wearable metallic button antennas, DBMBA [7] (a top loaded monopole on a small ground plane having a metallic button shape), Fig.1.

Section II describes how the 3D animated model is created. Section III explains how measurement has been taken in this study. This is for both on the main test model and also for the other 5 human models. In section III(B), a test is presented to establish that measurements taken on the original model are generally applicable to other people of roughly the same height. This is achieved by comparing the simulated model channel with measurements taken on 5 other similar height human models. Section IV provides simulated results to compare with the measurements presented in Section III. The conclusion section summarizes the agreement between the simulated body channel and measurement to give confidence in its use.

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II. METHODOLOGY

The detail process of how to create a 3D animated human model can be found in [5]. The process involves the following:

A. Scanning the human body

A test subject surface was scanned using a 3D scanner; this can be seen in Fig. 2.

B. Capturing body gesture and antenna position while measuring the body area network radio channel

The test subject wore skin tight clothing with 53 passive infrared reflecting markers to identify joint movement. A VICON Motion capture system with 8 cameras was used to track movement of the body as well as the antenna positions. This can be seen in Fig. 3.

The motion capture system and the body area network radio channel measurement was synchronized through a synch pulse generated from the motion capture system to trigger a Rohde and Swartz ZVB8 network analyzer which measured while the body gesture was captured.

C. Creating a 3D animated model and a 3D model of human movement for EM simulation

After post-processing of the 53 marker data in the motion capture, the system generated an animated skeleton representing the body gestures of the test subject. The location of the 5 markers around each antenna was used to determine each antenna location with respect to the body surface.

AutoDeskMaya was used to create a 3D animated model by combing the animated skeleton and the 3D body surface.

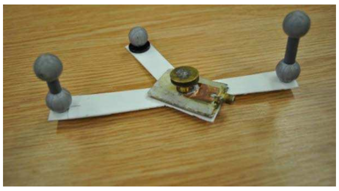
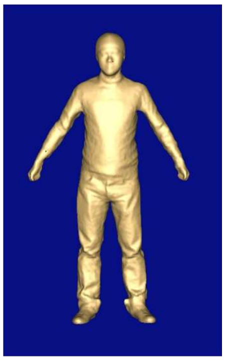


Figure. 1 The Dual Band Metallic Button Antenna surrounded with 5 markers to determined its position [8]

(a)



(b)

Figure. 2 (a) A test subject standing inside the 3D scanner system (b) A 3D surface scanned of a test subject

Finally, the selected frames of the interested gestures were converted into a 3D solid model using a CAD geometry translation program called 'Mesh2Solid'. The converted solid model in .sat format was then imported into XFdtd to be used for simulation. The antenna location could be determined from the coordinates of the 5 reference marker positions around the antennas.

III. MEASUREMENT

This study aims to evaluate how well the created 3D animation model can be used to represent the body area network radio channel of other people rather than the original test model that the avatar had been directly created from.

All measurements have been done in a production studio due to the need to use motion capture system so the effect of multipath propagation especially ground reflection would appear in the results; measurement results presenting here are the average of 5 measurement sets. Two measurement processes were used:

A. Main test model measurement

The main test model had one DBMBA radiating at 2.45 and 5 GHz bands, attached to his right wrist and another identical DBMBA was located on a plastic pole away from the test subject. Each antenna was mounted on a plastic frame having 5 reference markers as seen in Fig. 1 to track its position.

The model then performed a 5-step-walking action toward the plastic pole starting from a standing still position with both legs together. The second position was to move his right leg forward then followed by left leg forward as the third position. Then positions 4 and 5 are repetitions of right leg and left leg forward, respectively, Fig.4.

B. measurement on 5 additional humans

It was necessary to evaluated how well the original 3D animated model created using the proposed method represents off-body radio channels for other people than the original test subject. The authors have used the assumption that one of the critical factors causing difference in off-body channel S21 for different people is the height of the subjects.

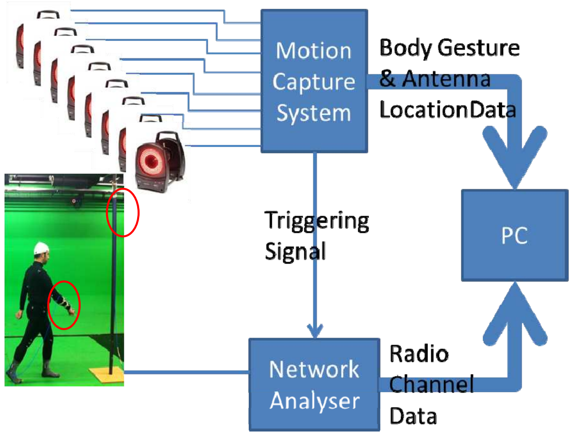


Figure. 3 The setup of a system to collect data of body gesture, antennas location and body area network radio channel

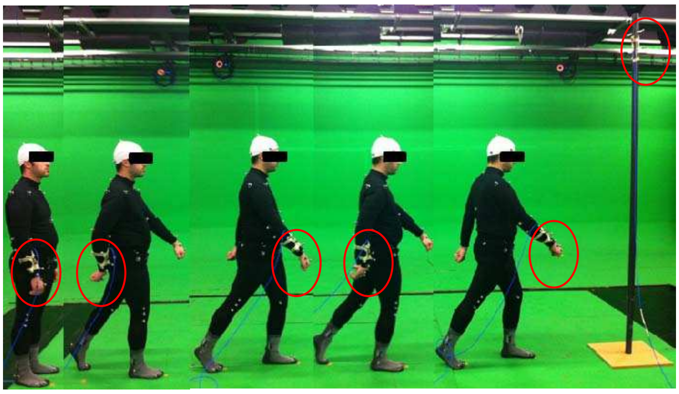
In order to eliminate this variable from the study, five additional test models were selected based on their similarity of height to the original model. The chosen models had height not 5cm more/less than the original model. Table I shows the height of each model. Each of the five new models performed the same movement of 5-step-walking as described in section A. Again, the off-body radio channel was measured.

Figs. 5-7 show measured and simulated S21 results in three actions (Position 1: standing 2 legs together; Position 3: left leg forward; and Position 4: right leg forward). The original test model results are indicated with solid and dashed lines, respectively. The 5 different symbols from TABLE I are used to display the S21 curves of the 5 additional models.

The main focus of this study is at two bands, 2.45 and 5-6 GHz, highlighted in two red circles in Figs.5-7, which are the matched frequencies of the DBMBAs. The results show the measurements from all 5 additional models are within 5dB of the main model in the antenna bands.

IV. SIMULATION

Simulations of the gestures of interest were done in the Remcom XFdtd, Finite Difference Time Domain simulation tool, using the created 3D solid model described in Section II. The 3D solid model had the exact body shape as the main model and the same gestures as those of the main model during radio channel measurement for each position. The 3D model was homogeneous with a relative permittivity equal to 35.15 which is equivalent to 2/3 of Muscle tissue relative permittivity value at 2.45 GHz. The conductivity was 1.1592 Siemens per metre.



1 2 3 4 5

Figure. 4 The main test model wearing a DBMBA on his right wrist performing 5-step-walking toward another DBMBA attached on a plastic pole while the body area network radio channel is being measured

TABLE I. HEIGHT OF EACH MODEL

Model ID	Height (cm)
Person1 ●	173
Person2 ■	171
Person3 ▨	170
Person4 *	166
Person5 ▲	165

The grid cell size of the model was set to 4 mm in all directions (x, y, z) and 0.7 mm for the antennas. A Perfectly Matching Layer (PML) was used as the absorbing boundary condition for every boundary around the simulation space. The time step value varied between 57 to 61 ps due to difference in simulation space size of each simulation case. The termination criterion was when the simulation reached a -30 dB convergence threshold [9].

In order to represent the multipath propagation environment of the production studio which was used during the measurement process, an 8 mm thick rectangular concrete floor with 86 cm width was placed underneath the 3D model. The maximum length of the concrete floor was set to 346 cm to ensure it extended behind the subject at the furthest distance from the transmitting antenna. The concrete material had a relative permittivity value of 4 and 0.015 Siemens per metre for conductivity.

The simulated results from the main model phantom are shown with dotted lines in Figs. 5-7. By comparing measurement and simulation (solid and dotted lines), one can see that they are well matched especially in the 2 bands of interest where the difference between them is less than 5 dB in all cases.

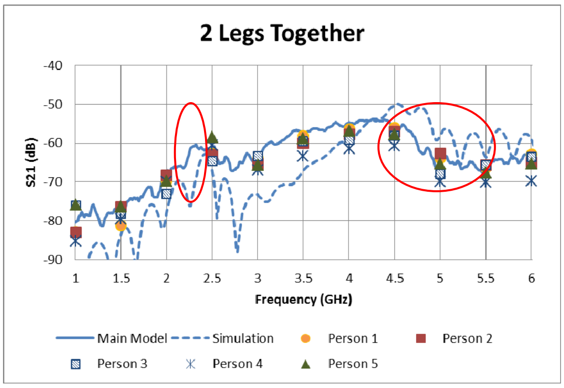


Figure. 5 Comparison of measurement of “2 leg together” position between the main model and five additional models with similar height

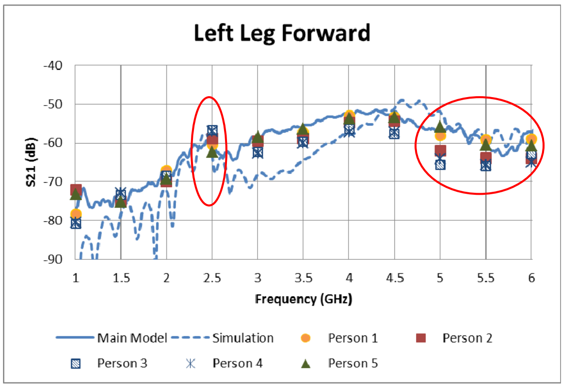


Figure. 6 Comparison of measurement of “Left leg forward” position between the main model and five additional models with similar height

In addition, following the agreement observed in Section III B, this would mean that the S21 measurements of the 5 additional models are also not much different to the simulated results.

The ripples seen in Figs. 5-7 appear in both measurement and simulation results. In the measurement, this occurs due to multipath propagation. While, all multipath environments could not be realized in the simulation since this would complicate the simulation problem too much which would lead to much longer simulation time, a dominant component of the multipath environments was ground reflection and this was considered by adding a concrete floor underneath the human model in every simulation problem. A lower ripple amplitude is noticed in the measurements than for simulation which is due to the fact that the average of 5 measurement sets is being presented here. Even though, the averaging process has reduced the strength of ripple in measurement, it can be seen clearly in the raw measurement data.

TABLE II shows both cases have the same trend of standard deviation but the difference between the other 5 measurement results to the main model measurement is less than in the simulation. Height is somewhat a factor in S21 alteration e.g. Model1 has higher standard deviation in both measurement and simulation than Model2.

On the other hand, Model3 has higher standard deviation in both cases than Model2 even though the height of Model3 is closer to the main model than Model2. After checking video recorded during measurement, it was clear that Model3 and 4 moved their arms very little compared to the other models which led to greater variation in S21 than the main model.

V. CONCLUSION

An evaluation of a created 3D model in various walking stances has been done by comparing simulation results of the main test model to measurement results of 5 additional models of similar height to the original model. The results have shown that the S21 curve from the simulated model can be used to represent the S21 of the other models in general, provided that they are similar in height to the model that the avatar was originally created from.

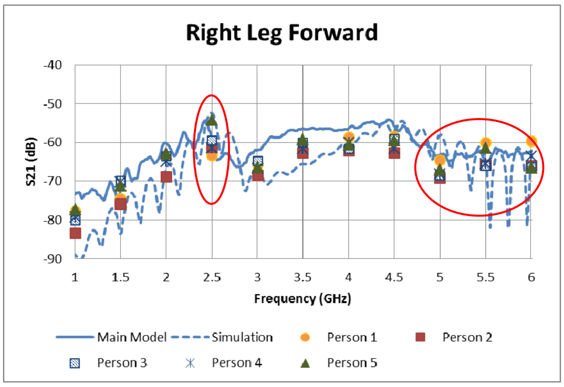


Figure. 7 Comparison of measurement of "Right leg forward" position between the main model and five chosen models with similar height

TABLE II. RELATIONSHIP BETWEEN HEIGHT VARIATION OF OTHER 5 MODELS AND STANDARD DEVIATION OF ITS S21DIFFERENCE AVERAGING OVER 5 INTERESTING GESTURES TO THE MAIN MODEL MEASUREMENT AND SIMULATION RESULTS

Model	Height difference to Main Model (cm)	Measurement Standard Deviation	Simulation Standard Deviation
Model1	5	3.21	6.03
Model2	3	3.07	5.10
Model3	2	4.00	5.83
Main model	0	0.00	3.92
Model4	-2	4.24	6.62
Model5	-3	2.32	4.52

In addition to height of the model, the distance between the two antennas also determines S21 value which means difference degree of arms movement between each model would lead to difference S21.

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